Long-term Lunar Radiation Degradation Effects on Materials

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Abstract

The National Aeronautics and Space Administration (NASA) is focused on developing technologies for extending human presence beyond low Earth orbit. These technologies are to advance the state-of-the-art and provide for longer duration missions outside the protection of Earth's magnetosphere. One technology of great interest for large structures is advanced composite materials, due to their weight and cost savings, enhanced radiation protection for the crew, and potential for performance improvements when compared with existing metals. However, these materials have not been characterized for the interplanetary space environment, and particularly the effects of high energy radiation, which is known to cause damage to polymeric materials. Therefore, a study focusing on a lunar habitation element was undertaken to investigate the integrity of potential structural composite materials after exposure to a long-term lunar radiation environment. An overview of the study results are presented, along with a discussion of recommended future work.

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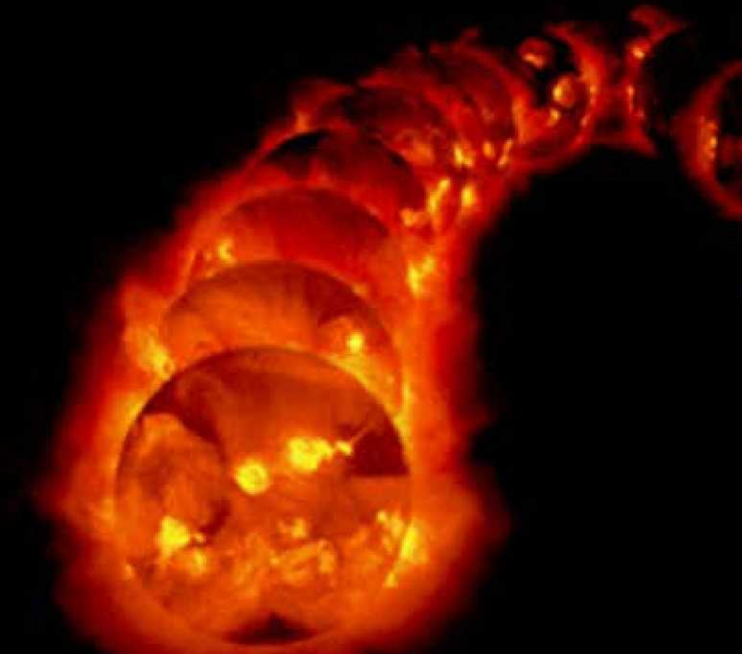

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Outline

- Introduction
- Background - Radiation
- Methodology and Test setup
- Some Project Results
- Ongoing Work
- Questions

INTRODUCTION

Introduction

- NASA is focused on technologies that will extend human presence beyond low earth orbit (LEO)
  - To advance state of the art
  - To provide for longer duration missions outside LEO
- Focus: materials for long-term surface habitation

Motivation/Purpose

- Long-term surface habitation requires large structures that must withstand the environment for the duration of the missions
- Fiber reinforced composites have gained interest
  - Potential weight savings
  - Potential enhanced radiation protection for the crew and electronics
  - Potential for infusing cutting edge research

Problem/Objectives

- Problem: composite materials have not been characterized for the space radiation environment, which is known to cause damage to polymeric materials

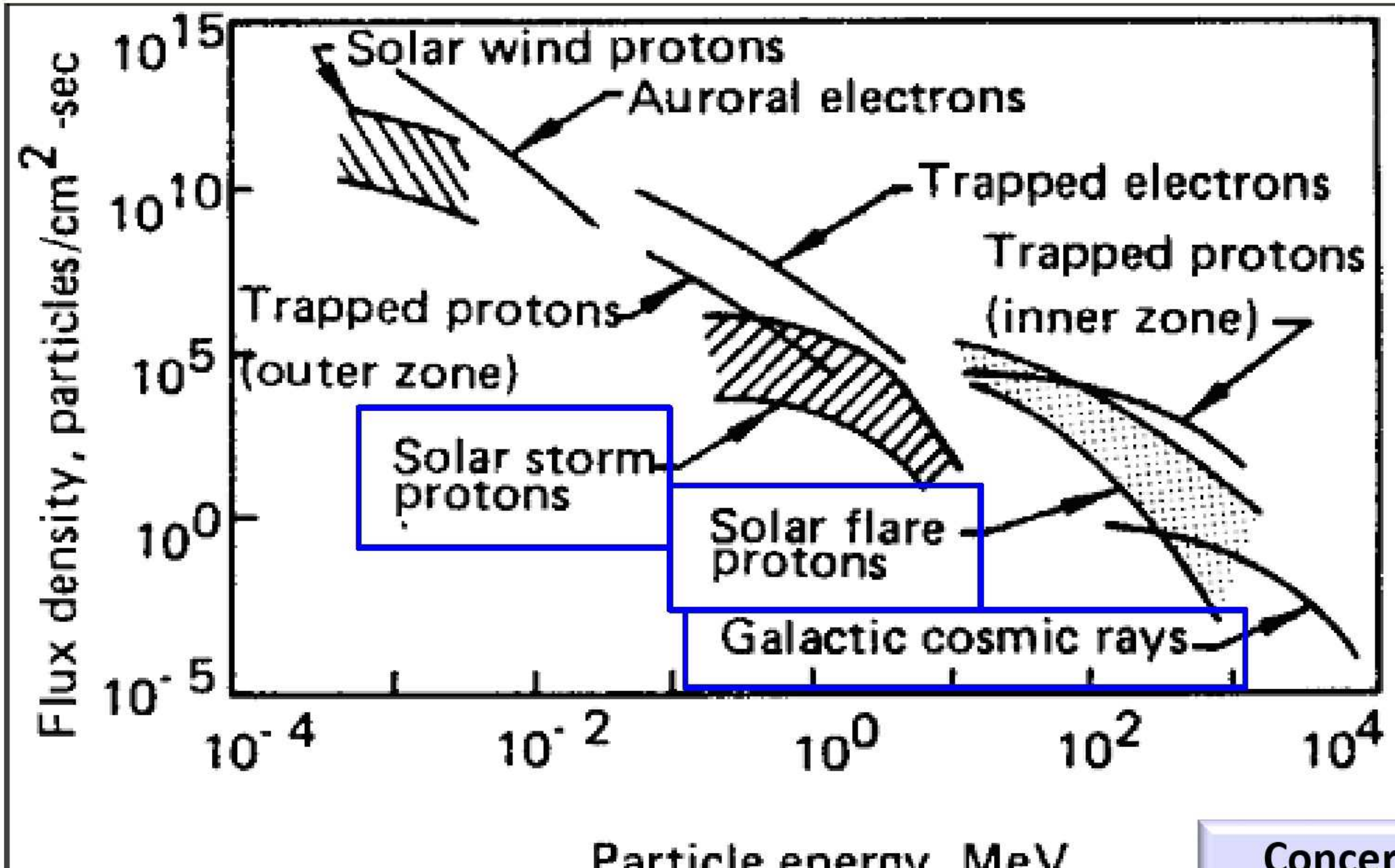
- Objective: assess composite durability in a simulated long-term lunar radiation environment

Assumptions

- The habitat is unshielded from radiation on the exterior
  - There is some multi-layer insulation and micrometeorite/surface ejecta shielding, but no galactic cosmic ray shielding (i.e. covering the habitat under regolith)
- The habitat will remain on the surface and be in service for 30 years
- The habitat is pressurized with air at an elevated oxygen concentration
- The habitat is exposed to one large solar particle event during each solar cycle and constant galactic cosmic ray exposure

BACKGROUND

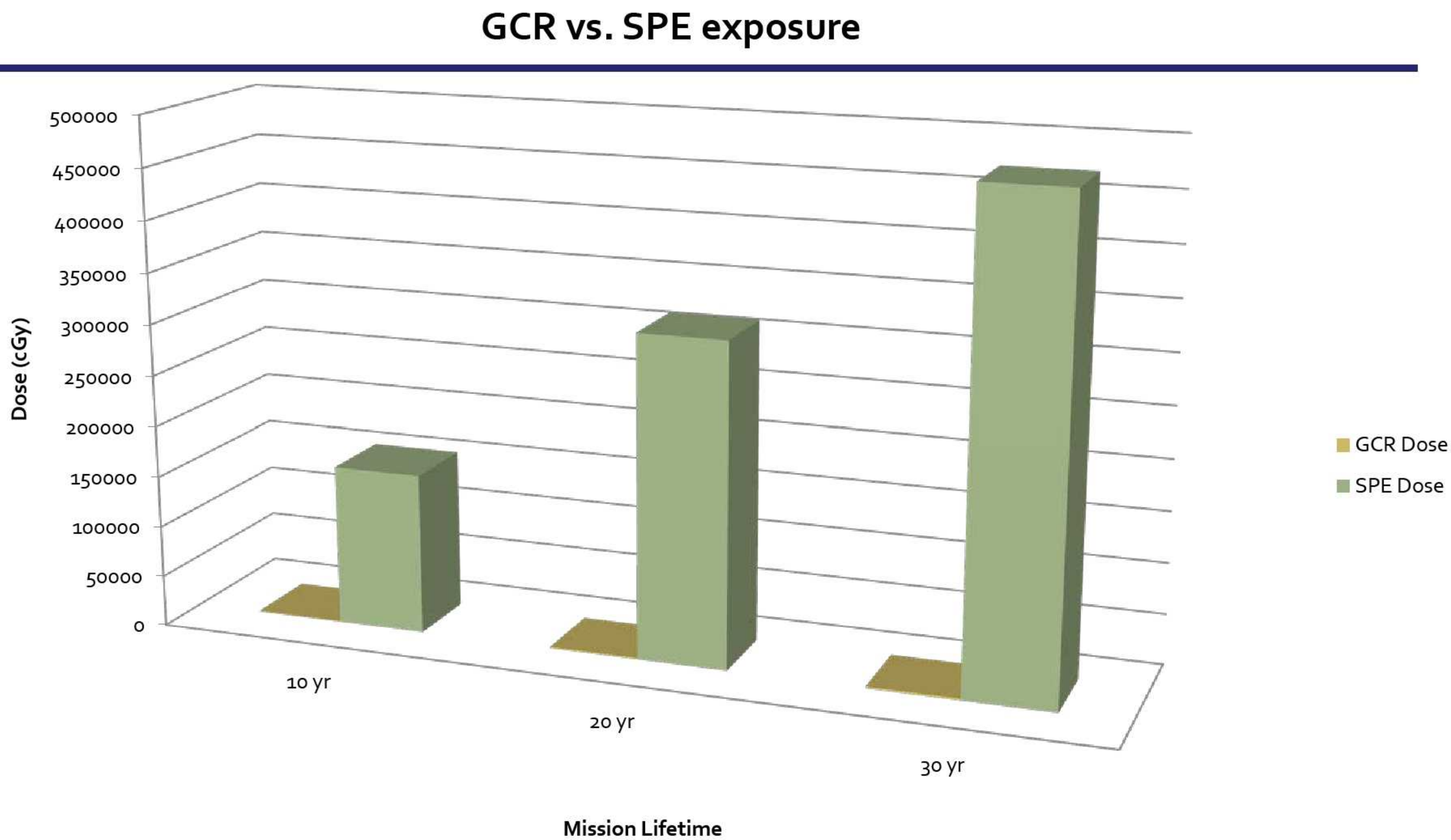
Background – Radiation Environment



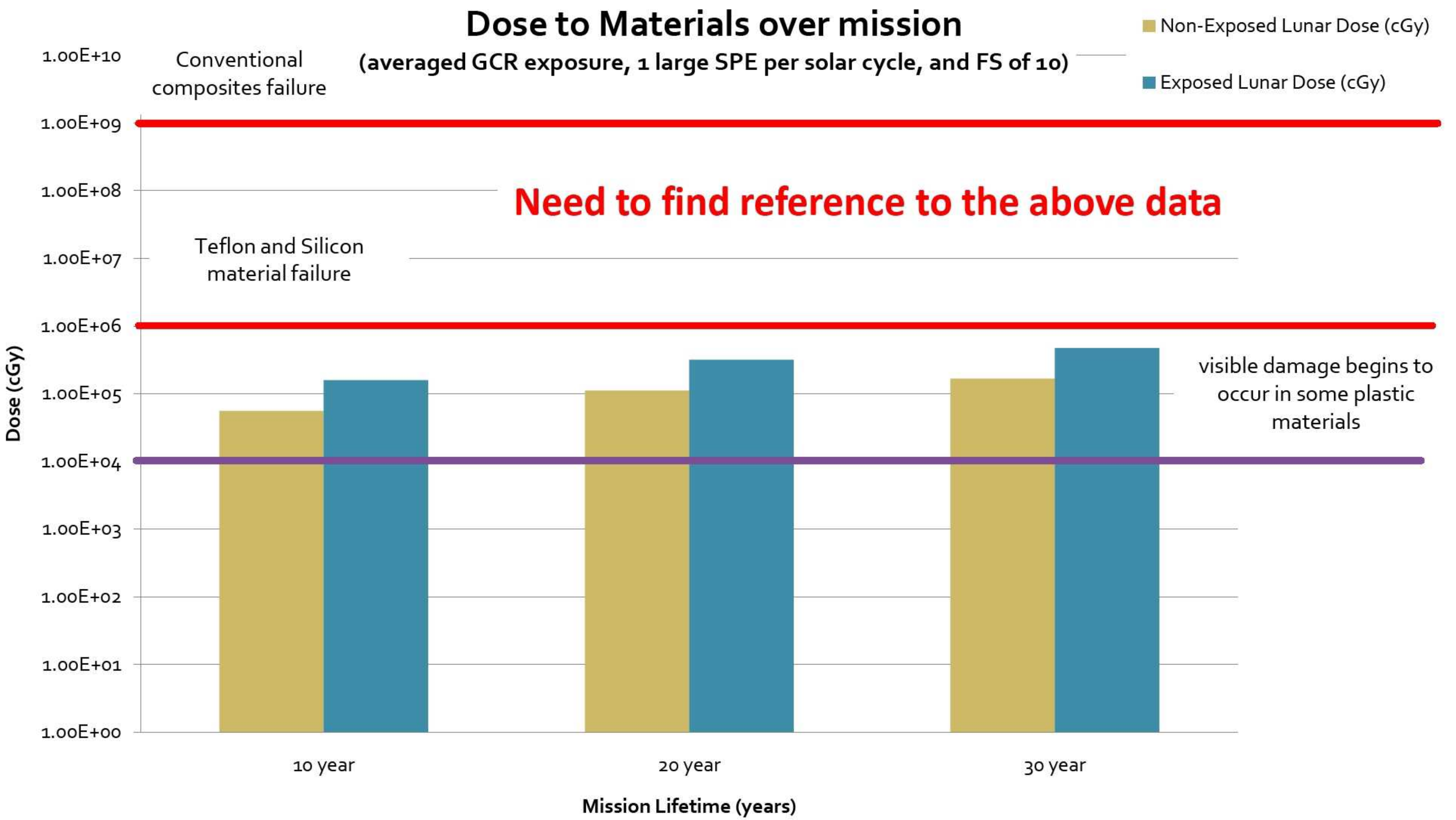
msis.jsc.nasa.gov/sections/section05.htm

Concerned with high energy particle radiation

Dominant Radiation on the Lunar Surface



Doses Materials will See Due to this Radiation Exposure

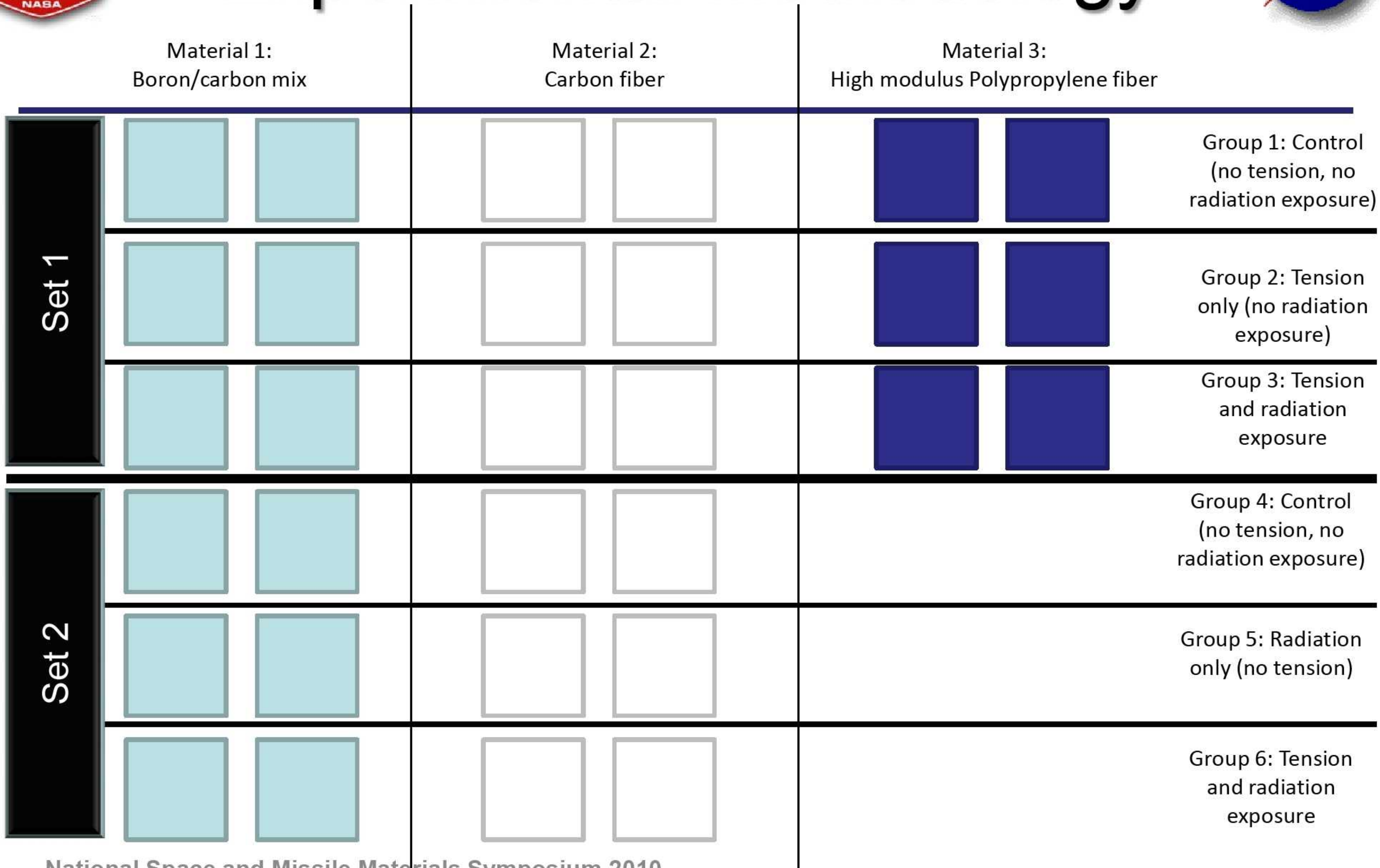


Radiation Effects on Polymeric Materials

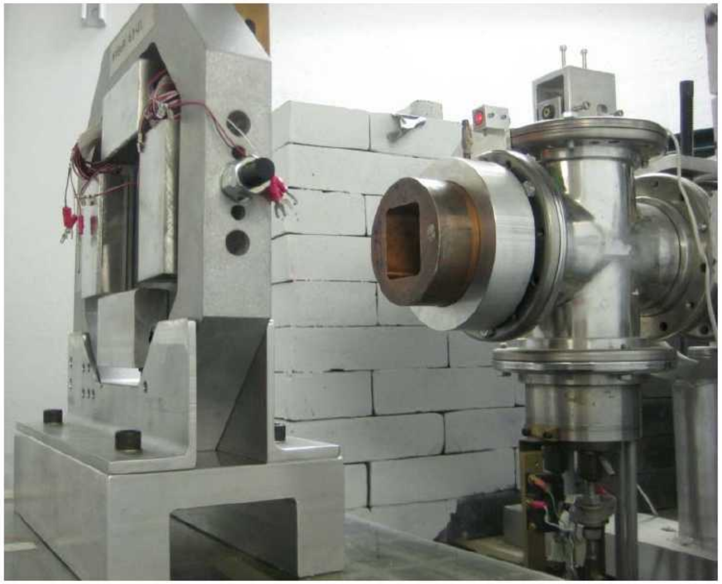
- Previous radiation research on polymers is mainly electron radiation or gamma radiation
- Cross-linking – bonds that link one polymer chain to another through chemical reaction
  - Pro: increases stiffness of material, potentially making it stronger
  - Con: if the stiffness is increased too much, the material becomes brittle and easily fractured
- Chain scission – a chemical reaction that breaks the bonds of the backbone polymer chain
  - Con: weakens the polymer strength

METHODOLOGY AND TEST SETUP

Experimental Methodology



Radiation Test Set up



Radiation Beam

Strain gauge in center of sample – gather a pre-exposure and post-exposure reading

Sample in Test Stand

Beam Exit

Characterization Completed

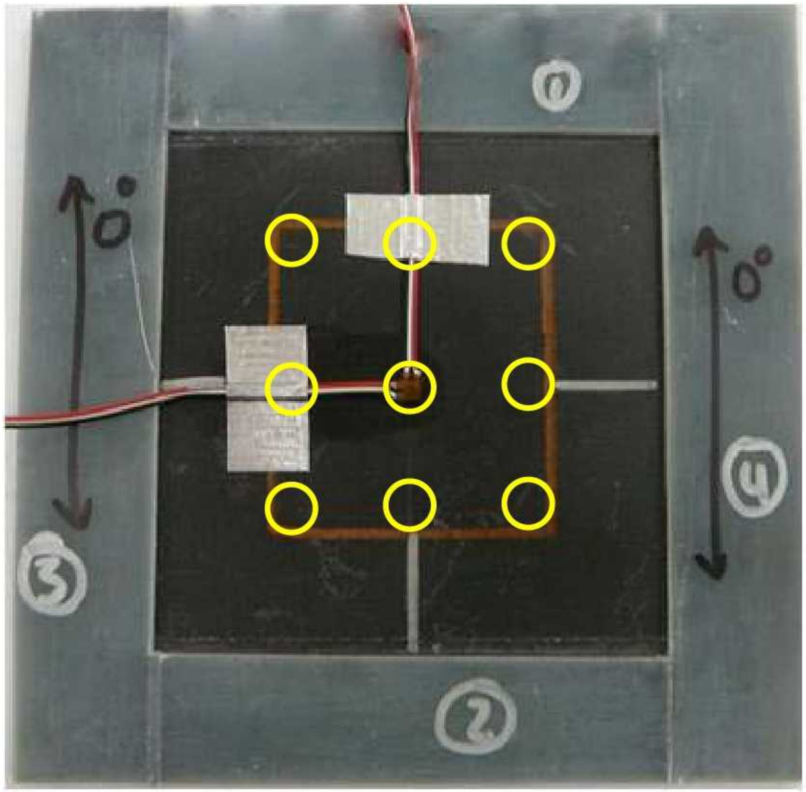
- Non-Destructive :
  - C-scan
  - Fourier Transform Infrared Spectroscopy (FTIR): bulk chemical composition
  - Raman Spectroscopy: bulk chemical composition (better for Carbon)
  - Scanning Electron Microscopy (SEM): look at surface for visual changes

Characterization Completed

- Destructive
  - Tension: tensile stress, strength, strain, ultimate strain, chord modulus, poisson's ration, stress vs. strain
  - Flexure: Flexural stress, strength, offset yield strength, chord modulus, strain, tangent modulus of elasticity, secant modulus, stress vs. strain
  - Dynamic Mechanical Analysis (DMA): Creep and/or stress relaxation information
  - Gas Chromatography - Mass Spectrometry (GCMS): analysis of compounds and molecular weight information
  - Optical microscopy: look at edge of sample to gather fiber volume fraction and porosity
  - Thermogravimetric Analysis (TGA): weight change as a function of time
  - Differential Scanning Calorimetry (DSC): heat capacity as a function of temperature, and changes in glass transition temperature
- Post-Fracture Analysis: Scanning Electron Microscopy (SEM): look at fracture edge after tension/flexure tests

SOME PROJECT RESULTS

FTIR Procedure

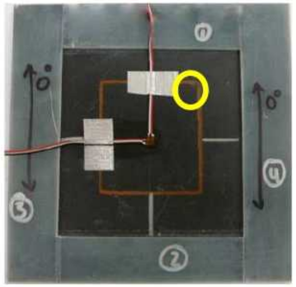


- Before radiation exposure, each sample was characterized by FTIR in 9 locations

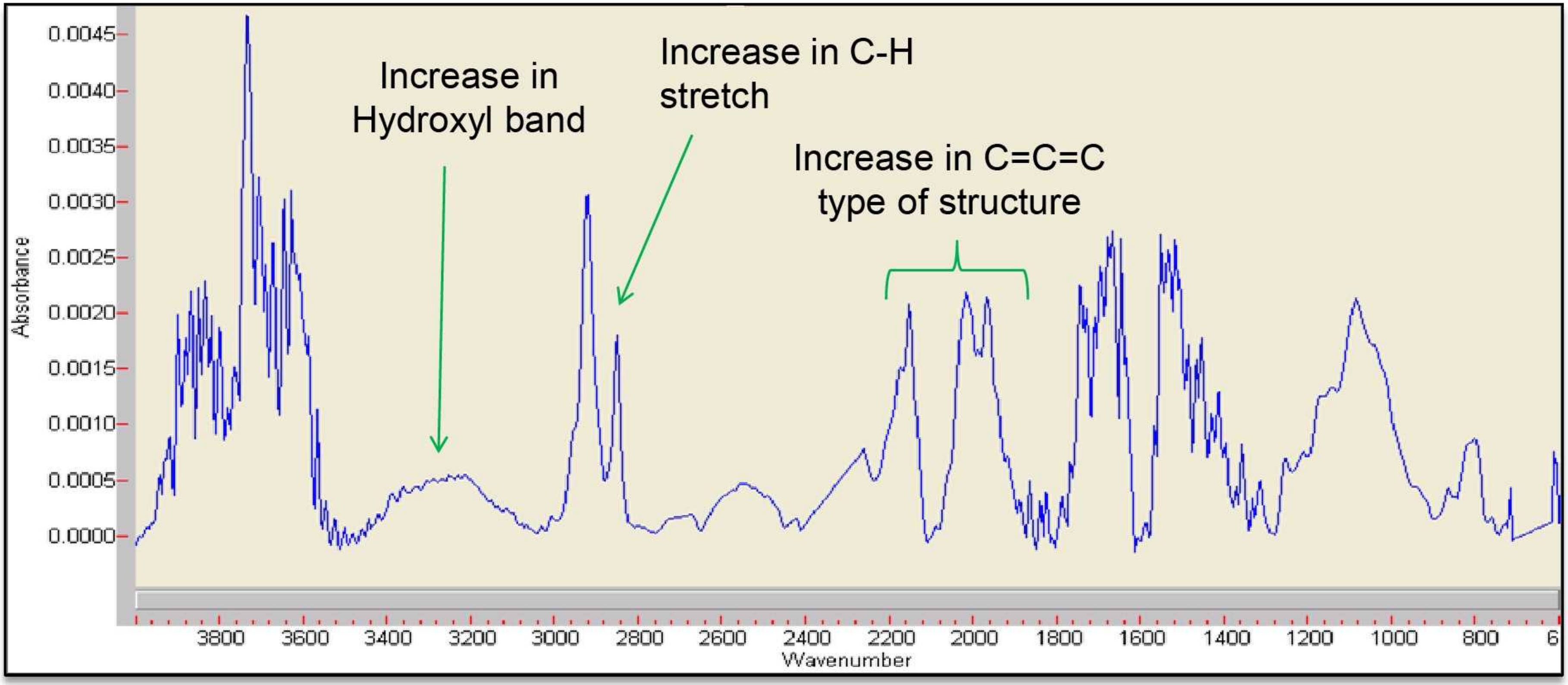
- After radiation exposure, each sample was again characterized by FTIR in the same 9 locations

- The pre-exposure scan was subtracted from the post-exposure scan to better locate new signals observed after radiation exposure

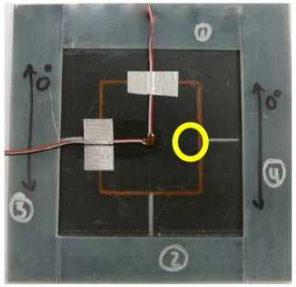
FTIR Results – Boron/Carbon



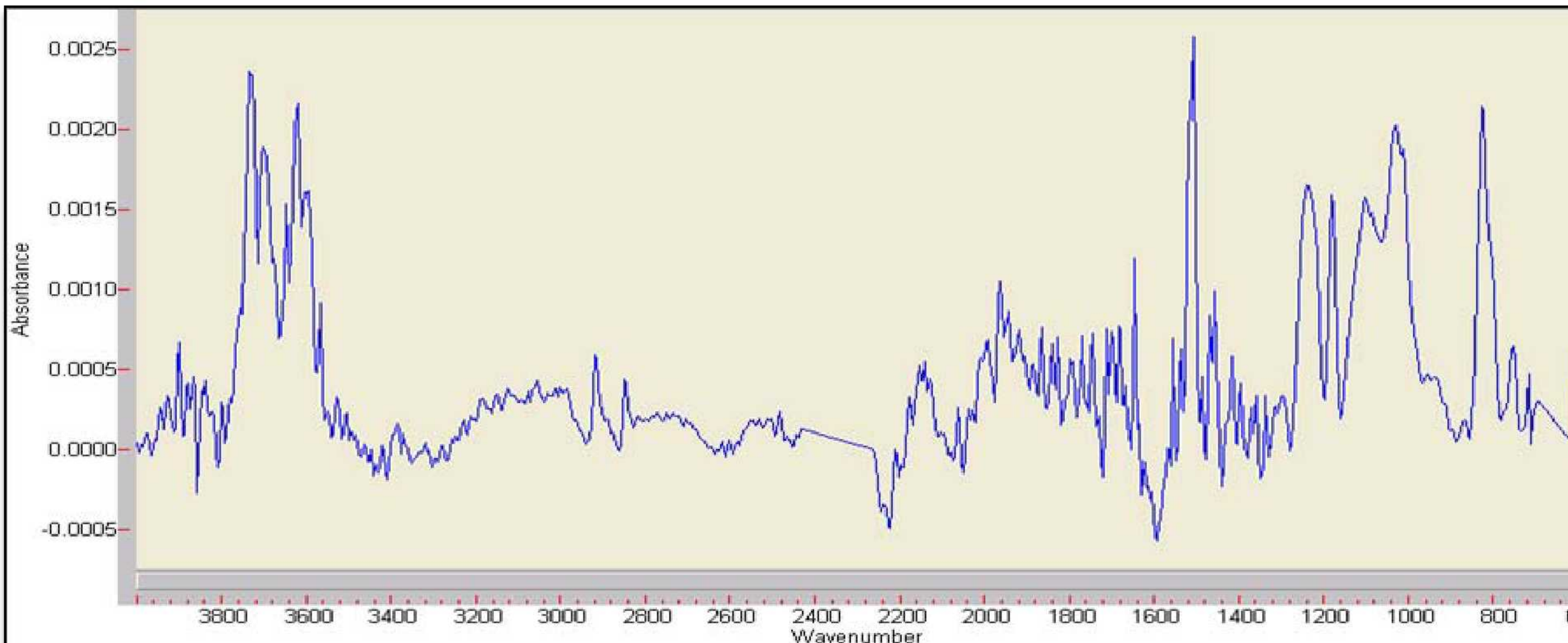
Potential supporting evidence for destruction of aromatic network structure.



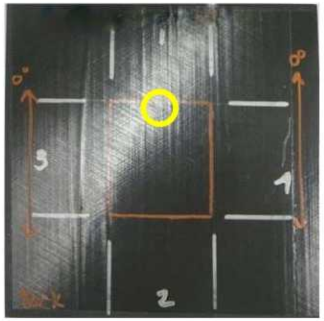
FTIR Results – Boron/Carbon



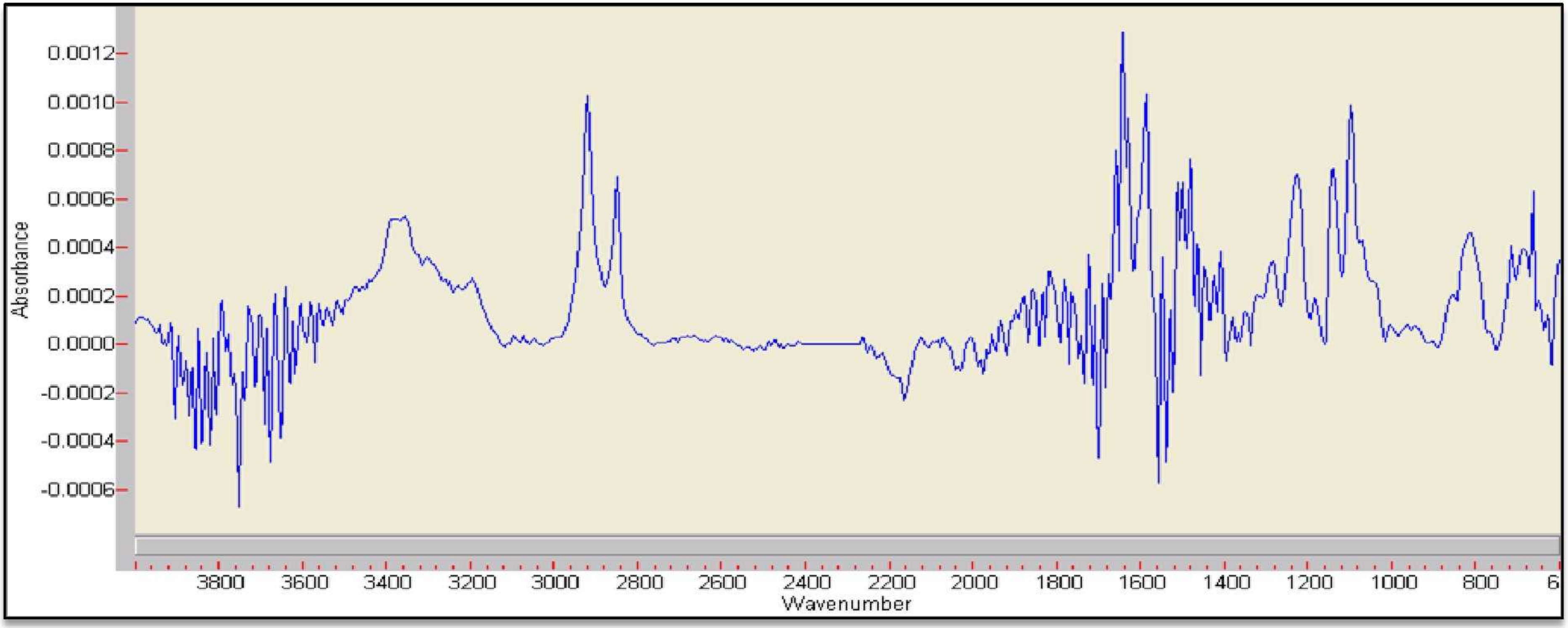
Aromatic structure is intact and no other structural changes are visible.



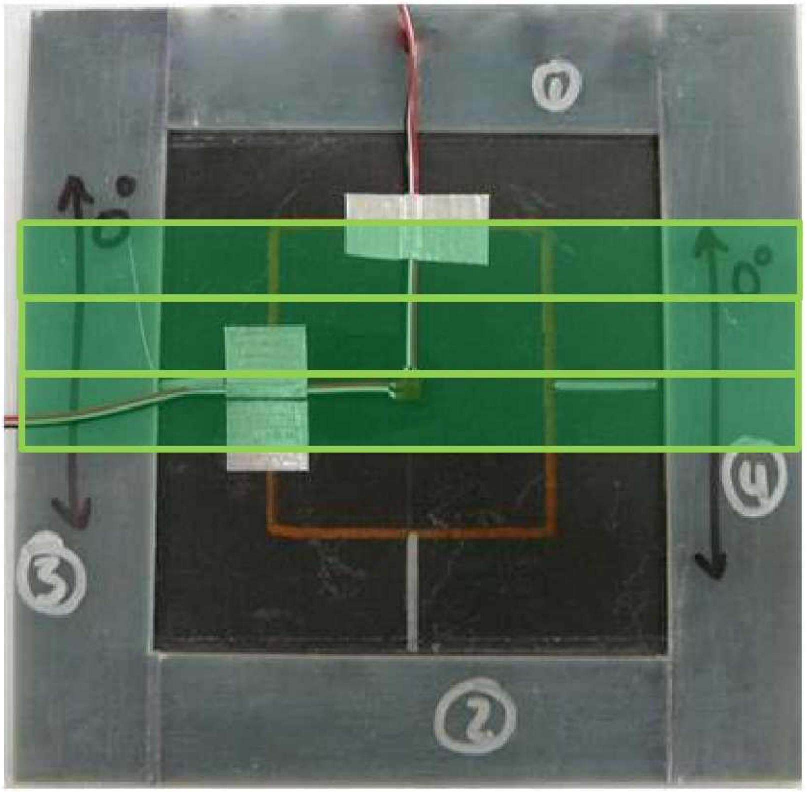
FTIR Results - Carbon



Aromatic structure is intact and no other structural changes are visible.

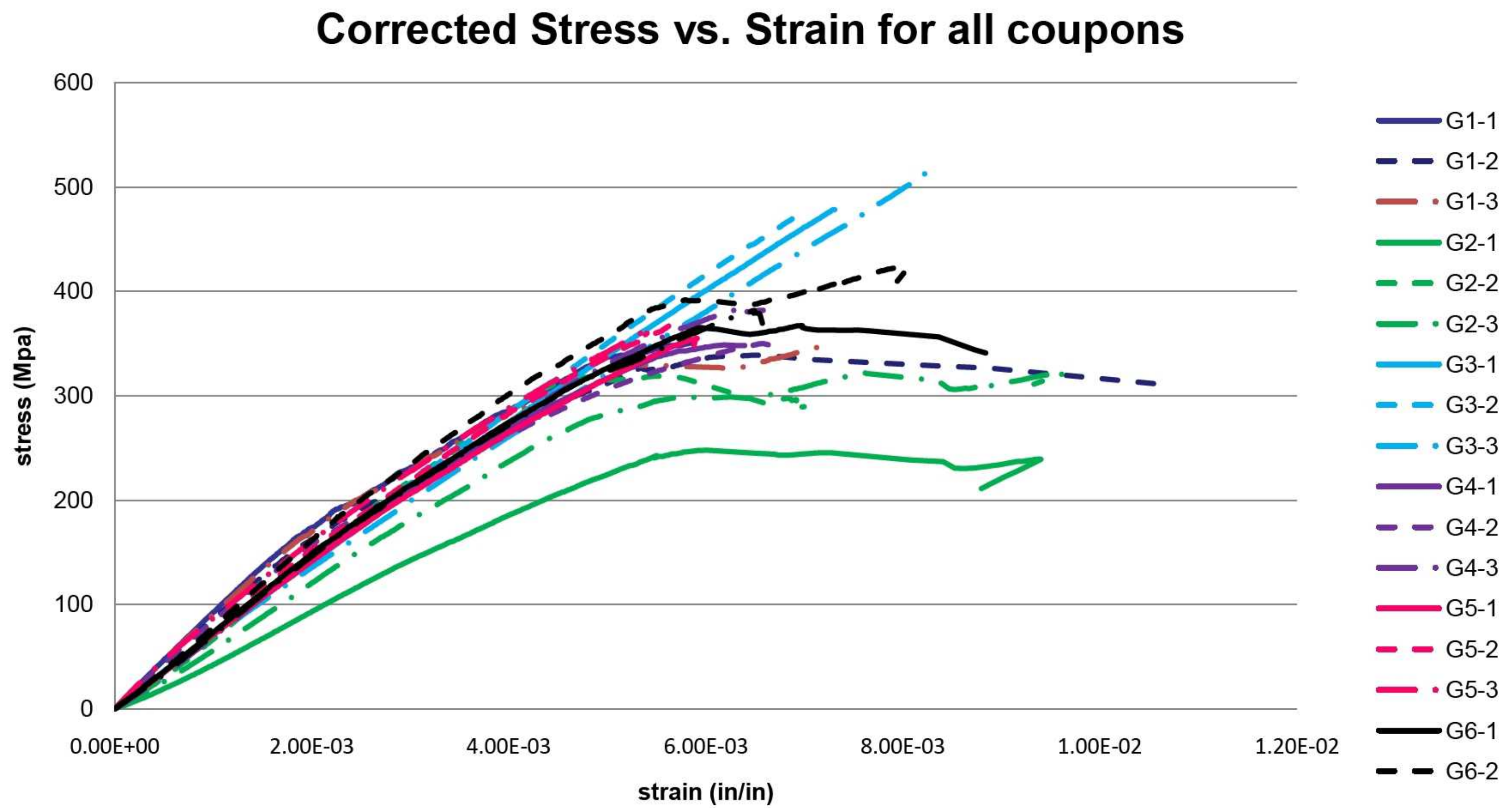


Tensile Test Procedure



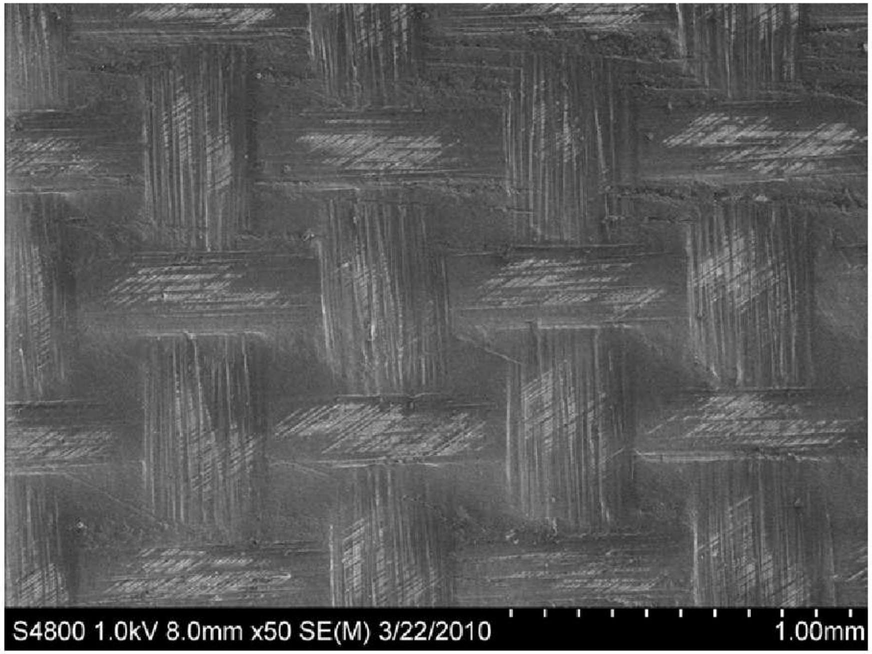
- 3 coupons made from one sample
- coupons were cut perpendicular to 0° plys
    - to highlight any matrix sensitivities in tensile properties
- Each tensile coupon included
    - tabs to protect the material during test
    - single strain gauge in the center to collect tensile data

Tensile Results – Boron/Carbon

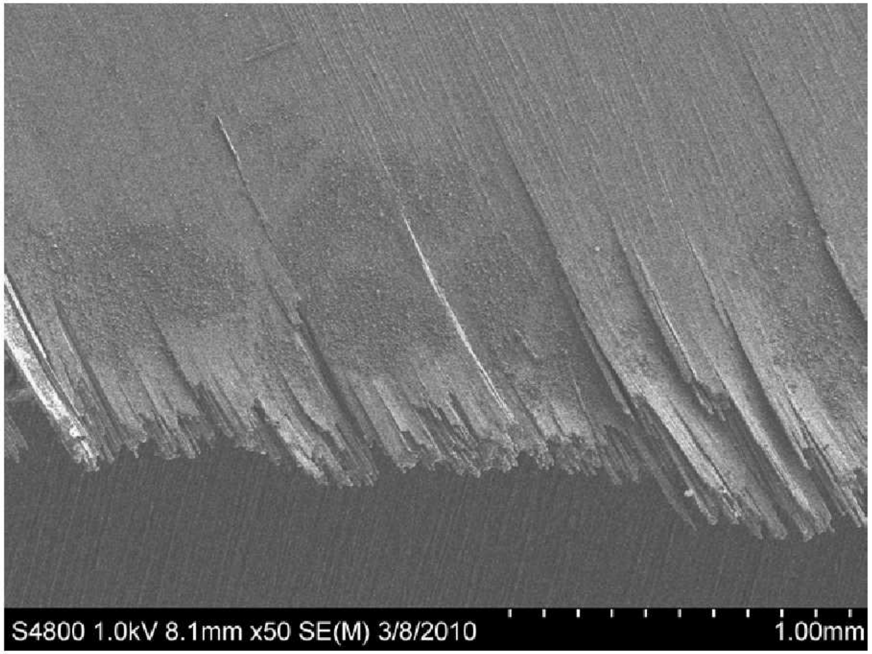


SEM of Fracture Edge – Boron/Carbon

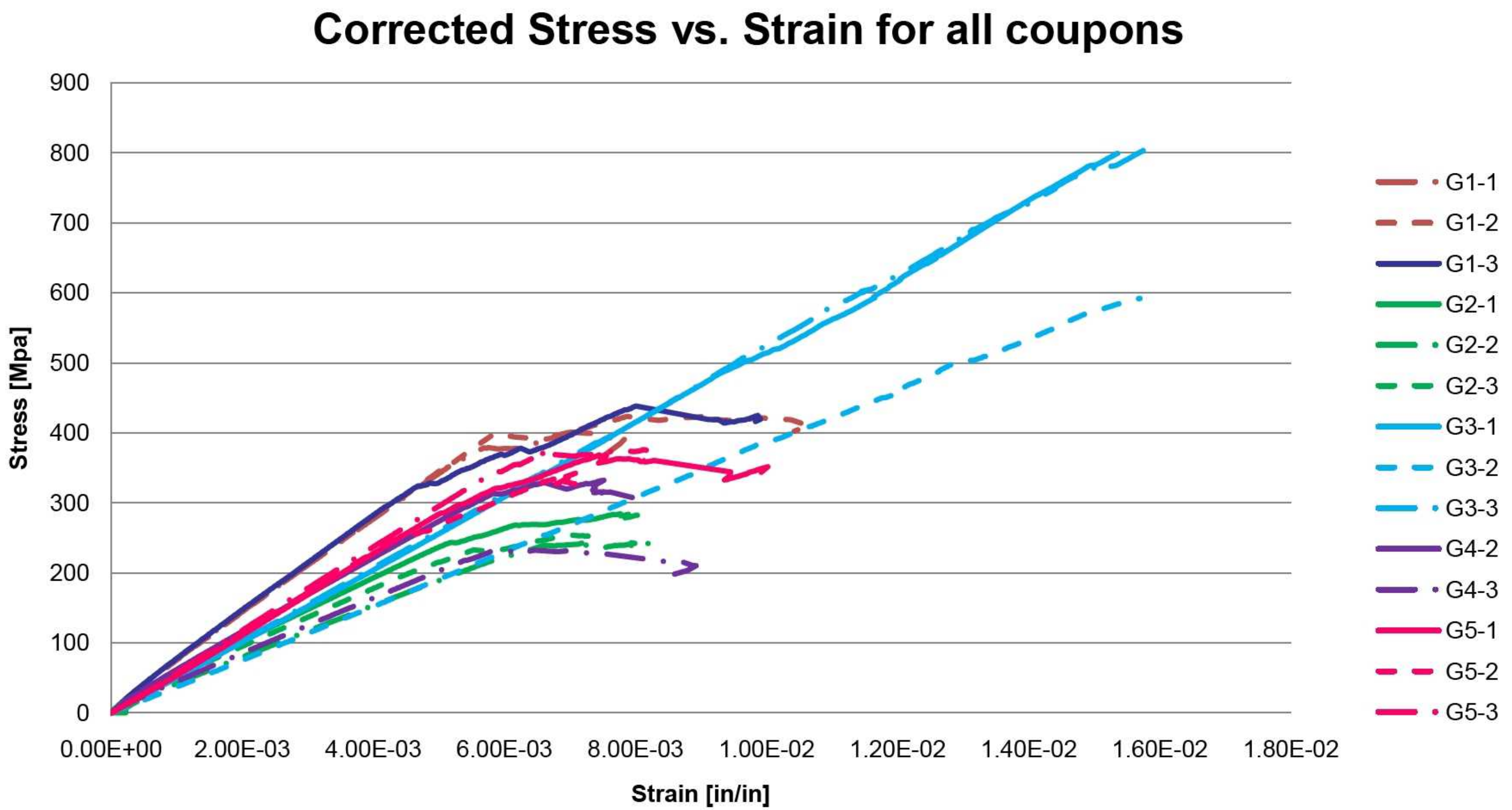
Control – Surface Micrograph



Radiation and Tension – Surface Micrograph



Tensile Results – Carbon



Ongoing Work

- Continued data analysis of coupons already characterized
- A new study looking at the dose rate during radiation exposure and its effect
- A new study looking at how irradiated composites respond to hypervelocity impacts

Summary – Boron/Carbon

- FTIR
  - Possible evidence of destruction of aromatic network structure
  - Possible evidence of oxidative degradation
- Tensile
  - Possible evidence of enhanced cross-linking of the matrix
- SEM
  - Possible evidence of surface damage

Summary - Carbon

- FTIR
  - No evidence of changes yet
- Tensile
  - Possible evidence of enhanced cross-linking of the matrix

Conclusions and Future Work

- Data shows that something is changing the material properties, even though it is inconsistent at this point
- Continue to analyze collected data
- Further work needs to be completed
  - Validate repeatability of data
  - Increase data sets for statistical significance
  - Control variables of time and environment better

Acknowledgements

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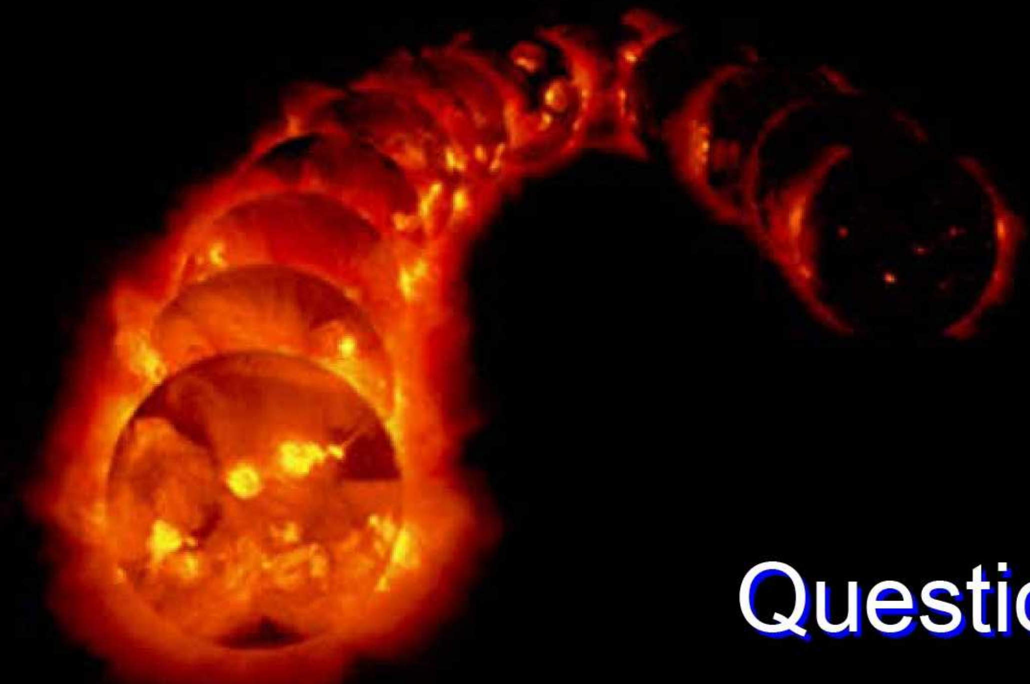
- University of Southern California
- The Boeing Company



Questions